9

Electric Railway Traction

Big Contract for Britain

AFTER months of wearisome negotiations with the Brazilian Government, the final stage of official intervention in the electrification of certain lines of the Central Railway of Brazil has been reached, and the contract formally signed with the Metropolitan-Vickers Electrical Co. Ltd., which firm is thereby made responsible for a programme of conversion from steam to electric traction valued at approximately **£3,000,000**. What proportion of the total work will be carried out in Britain, and what will be the duration of the contract, cannot be estimated until a number of technical questions are decided, but it is a credit to the perspicacity and technical ability of the leaders of the British electrical industry that a scheme of such magnitude should be entrusted *in toto* to this country at a time when all the world is on the look-out for orders which will provide employment over a period of months for a large body of workers. Particulars of the way in which the conversion is to be paid for are published on page **997** of this Supplement.

Axle Reactions and Weight Distribution

AMONG steam locomotive men it has never been widely realised that with ordinary nose-suspended motors the alteration in the weight distribution of an electric locomotive is often considerable, and that in many cases the effect could be decreased to almost negligible proportions by suitable design. The drawbar reaction must always be with us; it is present in steam locomotives, and in quite a number of **0-6-0** goods engines the weight on the trailing axle has been kept two or three tons less than the load on the leading and driving wheels, as the drawbar reaction tends to load the rear wheels. But the drawbar reaction in an electric locomotive of the rigid frame type can be taken up in the leading and trailing carrying wheels, if any, without alteration of the adhesion weight, and the same applies to the reactions from the motors, always assuming a suitable design. With double-bogie locomotives driven by nose-suspended motors the alteration in adhesion weight, due to the combination of drawbar and motor torque reactions, can never be eliminated, but as is shown on another page of this issue, in an article from the pen of a member of the Metropolitan-Vickers' traction department, it can be reduced to proportions which may result in important modifications being made to the general design of the locomotive. From the article mentioned, it will be seen what a variety of bogie suspension and motor arrangements are possible with the normal Bo-Bo wheel notation, and also that the usual layout with motors hung towards the bogie pivot, although very convenient from a constructional point of view, does not possess the most efficient adhesion characteristics. Considerable difficulty has arisen on more than one occasion with double four and six wheel bogie electric locomotives due to a variation in the axle load when exerting maximum tractive effort at starting. Once the wheel has started to slip, its coefficient of adhesion falls very rapidly, and the trouble is not remedied by a partial shutting off of current; the controller must be switched back momentarily to zero at just the time when maximum effort is needed.

Wheel Arrangements

THE nomenclature of electric, and incidentally, diesel-electric, locomotive wheel arrangements is a subject upon which something approaching general agreement has been reached in Europe and European-controlled countries without finality having been attained. In North America, too, there does not appear to be any internal conflict upon the matter, but the system favoured differs widely in some respects from that used on this side of the Atlantic, and on another page of this issue is published an article on American practice by a member of the Transportation Engineering Staff of the International General Electric Company, which firm was one of the pioneers in the adoption of the present system of notation. Although aware that the European system has its limitations, we think that the American method defeats its own object by endeavouring to include too much information which is not of the first importance in obtaining an idea of the locomotive lay-out. It is to be questioned whether the adhesion and total weights are of sufficient importance to include in a wheel arrangement formula, even though the former gives an idea of the maximum tractive force which might possibly be exerted. But if these weights are included, then why not the speed also?

A more important point, however, is the manner in which the motors are described. The fact that the number of motors is stated by a definite figure does not give any clearer idea as to whether they are axle-hung, gearless, or twin-armature type than does the suffix " o " of Continental parlance; in fact, the American system is more misleading than the European, because it is not always possible to tell at a glance whether or not rod drive is employed, and the number of motors must be checked against the actual wheel arrangement, which forms only the first part of the formula. In the best of cases it is no improvement on the system in use over here; neither can provide a definite formula, for example, for a five-axle locomotive driven by three nose-suspended motors, and having all axles coupled by side rods. Nor does there appear to be any definite value assigned to the figures representing the motors. Mr. Bearce does not mention in his article exactly what these figures represent, and although one or two examples which we have checked seem to indicate that this is the hourly output of each motor in horse-power, further examples can be found which appear to contradict this supposition. At all events, the hourly capacity is not of much use unless some indication is given of the corresponding speed. It has been suggested to us that this figure in the formula simply represents the makers' code number; we hope not, for this would render the whole expression valueless. We still hold that the prime purpose of any system of wheel notation is to give simply as accurate an idea of the wheel arrangement and the drive as is possible.

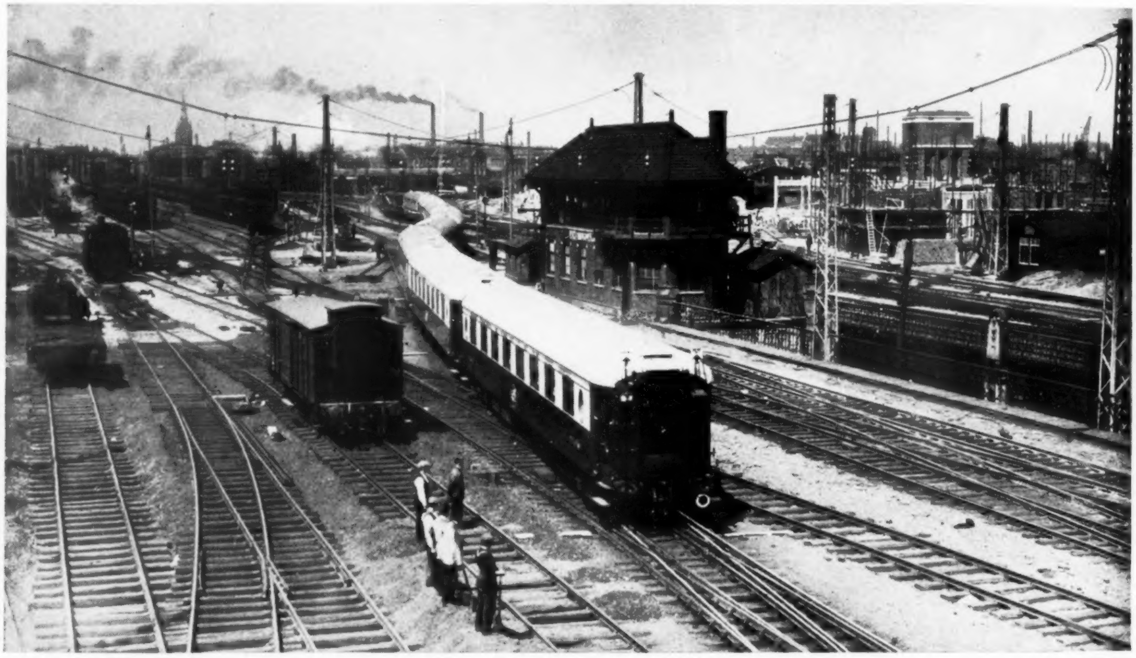
RAILWAY ELECTRIFICATION IN HOLLAND

Important extension brought into operation with commencement of summer time tables

ON May 15 there was opened to the public an electric service from Rotterdam (Delft Poort) to Dordrecht, which carries a fairly heavy suburban and week-end traffic, and taps a rapidly developing district. This brings up the electrified route mileage of the Netherlands Railways to 126, a figure which will be increased to 143½ miles when the Schiedam—Hook of Holland section is converted in 1935, and all of this is operated by direct current at 1,500 volts.

The electrification of the Dordrecht line was decided upon in 1926, and the conversion work has been carried out gradually over the intervening eight years. A heavy programme of improvements over the whole 12·5 miles from Delft Poort to Dordrecht was scheduled at the same time, and it has been these works which have taken up most of the time and accounted for the major part of the capital expenditure. The line is carried through Rotterdam on a series of bridges and viaducts, the strength of which was not sufficient to allow of the passage of the heaviest steam locomotives, and the international and main line trains between Rotterdam and the south and south-east had to be hauled through the city by lighter engines. All these bridges and viaducts have now been rebuilt or strengthened, and the Beurs station completely reconstructed. In place of the former three tracks and one island platform at this station, there are now two tracks and two platforms, over 600 ft. long, which are carried over the Beursplein on 68 spans. For part of their length, the feeder cables have been laid along the dried-up bed of the river known as the Old Maas, and the Dutch post office took the opportunity of laying telegraph and telephone cables there at the same time.

Practically no work except the erection of the electrification masts and overhead gear was required on the two great bridges over the Maas and the Konigshaven, but Fijenoord halt on the south bank of the river has been modernised, and plans have been drawn up for the erection a little further south of a large station to serve the needs of the southern portion of Rotterdam, although the construction has not yet been sanctioned. The intermediate stations on to Dordrecht are all being completely reconstructed in ferro-concrete, and an island platform substituted for the single up and down platforms at Barendrecht and Zwijndrecht. The last big work to be completed was the rebuilding of the bridge over the Waal at Barendrecht. Extensive alterations were necessary at Dordrecht station, where the three platform roads are electrified. The station offices and sheds have been rebuilt, and the platform length increased to approximately 400 yards.



View of Amsterdam Central station taken during the erection of the electric overhead gear. The train in the foreground is the steam-hauled Paris-Amsterdam express Etoile du Nord

Three new substations have been constructed at Schiedam, Fijenoord, and Zwijndrecht, and all are of the mercury-arc rectifier type. Schiedam substation is not situated along the Dordrecht section, but gives a better distribution of load over the lines in and around Rotterdam. The rectifiers are all of the steel-tank type, and the

standard unit has a rated capacity of 1,200 kW., with an overload capacity of 1,800 kW., for two hours and 4,800 kW. for 40 sec. Although the substations have no permanent staffs they are not remotely controlled, their operation being the responsibility of the staff at the adjoining station or signal box; this method is adopted, in general, over the whole of the electrified lines of the Netherlands Railways. Power is obtained from the central generating station at Rotterdam, which has supplied the Rotterdam-Hague line as far as Schiedam and Pijnacker for some years.

General System

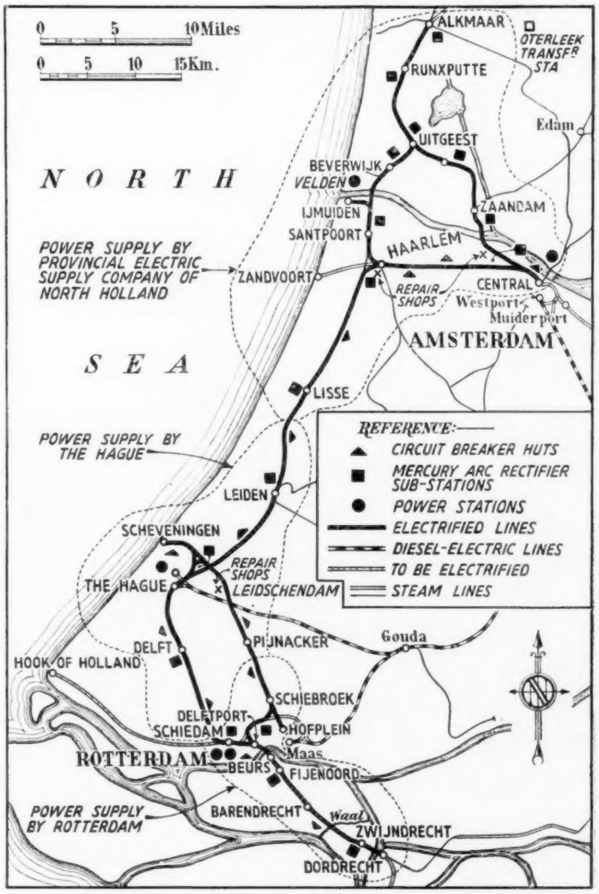
The electrification of the Netherlands Railways as it stood at the beginning of 1931 was described in detail in THE RAILWAY GAZETTE for February 20 of that year, but since that time further sections, totalling 30 route miles apart from the Dordrecht line, have been opened. These are the Amsterdam-Alkmaar and Velden-Uitgeest lines, the conversion of which was decided upon in 1929, in consequence of the favourable results obtained between Amsterdam, The Hague, and Rotterdam.

Electric traction in Holland commenced with the Rotterdam-Scheveningen line of the then South Holland Electric Railway. This 20-mile line ran from the Delft Poort station at Rotterdam to The Hague via Pijnacker, and was converted from steam to electric on the single-phase principle at 10,000 volts

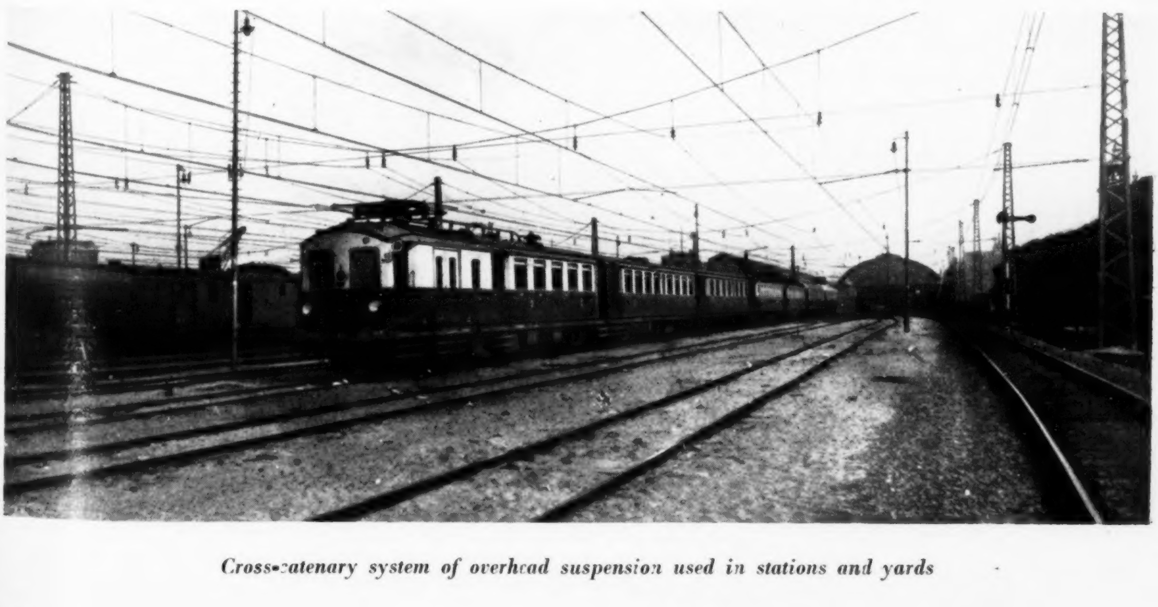
ELECTRIFIED LINES OF THE NETHERLANDS RAILWAYS, 1,500 VOLTS D.C.

Section	Date of Opening	Route Mileage
Rotterdam (D.P.) - Pijnacker - The Hague-Scheveningen*	Oct. 1, 1908	20·5
Haarlem-Ijmuiden	May 15, 1927	7·5
Amsterdam - Leiden - Rotterdam (D.P.)	Oct. 1, 1927	53·5
Rotterdam (H.P.)-Schiebroek ..	,,	2·5
Amsterdam-Alkmaar	May 15, 1931	24·25
Velden-Uitgeest	,,	5·5
Rotterdam (D.P.)-Dordrecht ..	May 15, 1934	12·5
Total route mileage		126·25
,, track ,, ...		319·00

* Electrified at 10,000 volts 25 cycles single-phase in 1908, and converted to 1,500 volts d.c. in 1926.



Map of electrified lines on the Netherlands Railways showing location of power and substations



Cross-catenary system of overhead suspension used in stations and yards

25 cycles. This system existed until 1926, when the working was changed to 1,500-volt d.c. to conform to the system adopted for the Rotterdam-Amsterdam and Haarlem-Ijmuiden lines, conversion work on which was then proceeding. After conversion to d.c., the old line of the South Holland Electric Railway, which had been merged in the Netherlands Railways after the war, was extended from Schiebrock to the Hofplein station in Rotterdam, and the services to Scheveningen via Pijnacker are now run from this terminus.

The dates of opening of the various electrified sections of the Netherlands Railways are given in the table on page 993. The date given for the Amsterdam-Rotterdam division refers to the opening throughout of this line owing to the opening of the Rotterdam-Dordrecht section, which is served by existing trains from Amsterdam and The Hague continuing on from the Delft Poort station.

Mercury-arc rectifiers have been installed in the substations since the inception of the post-war electrification programme, but the substation at The Hague also contains a couple of motor-generator sets, which are to be taken out when due for heavy repairs or renewals. The 17 substations are equipped with a total of 29 rectifiers, having a total continuous capacity of 38,000 kW. The original substations of the Rotterdam-Amsterdam section contained Brown-Boveri rectifiers, and the substations of the Alkmaar and Uitgeest extensions were also equipped with machines of the same make, with the addition of two rectifiers each

Four-car electric train at Amsterdam

Reinforced overhead construction for 1,500-volt lines

to express traffic. Actually, the 9·5 miles from The Hague to Leiden were fitted up first as an experimental line on which to test both the rolling stock and overhead equipment, and trials commenced in 1925. The Haarlem-Rotterdam portion was opened to electric service in March, 1927, and the branch from Haarlem to Ijmuiden in May of the same year.

Current is obtained from the power stations of the municipalities of Amsterdam, The Hague, and Rotterdam, and from a national station, the power supply being divided up over the areas shown in the accompanying map. All of it is received in three-phase form by the 17 railway substations, but the tensions vary between 5,000, 10,000, 25,000 and 50,000 volts at different points. The quantity of current purchased over the last six years has increased with the opening of new sections of line, as may be seen from the following figures:—

	Units		Units		Units
1928..	45,080,000	1930..	48,334,000	1932..	66,797,000
1929..	47,657,000	1931..	61,147,000	1933..	64,879,000

There will be a further increase during the present year, by the A.E.G. and Siemens-Schuckert. On the Rotterdam-Dordrecht section, International G.E.C. and Oerlikon rectifiers are being tried. One of the 1,000 kW. Brown-Boveri units installed on the Alkmaar section is illustrated in the article " Mercury Arc Rectifiers—III " appearing in another part of this issue.

On the Rotterdam-The Hague-Amsterdam section there were only seven substations until the erection of the new one at Schiedam, coincident with the conversion of the Dordrecht line. The Amsterdam-Alkmaar-Velden diversion has also seven substations, although the route mileage is only some 40 per cent. that of the former section, but in considering these numbers the provision of numerous circuit-breaker switch cabins between Amsterdam and Rotterdam, as shown on the map accompanying this article, must be remembered. At these cabins the overhead contact wires of the up and down lines, which are otherwise quite separate, are connected in parallel.

At six of the seven substations along the Alkmaar extension, the arrangement of the electrical equipment is the same. The seventh substation, at Uitgeest, is arranged

to take three-phase 50-kV. current from the power stations at Velden and Amsterdam and supply it at 10 kV. to the remaining substations by means of a cable system laid alongside the railway track. This was done in order to obviate the cost of expensive 50 kV. apparatus in each substation, and to prevent weakening the high-voltage system by putting numerous tappings on it. An additional 10 kV. cable is laid between Amsterdam power station and Zaandam substation, and from Oterleek transformer station to Alkmaar rectifier substation, the object of which is to act as a standby in case of serious trouble at Uitgeest substation. They then allow a restricted supply of power to flow to the 10 kV. cable system.

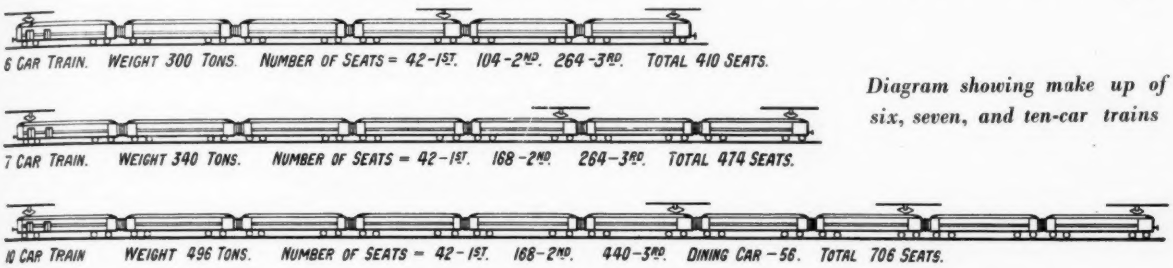


Diagram showing make up of six, seven, and ten-car trains

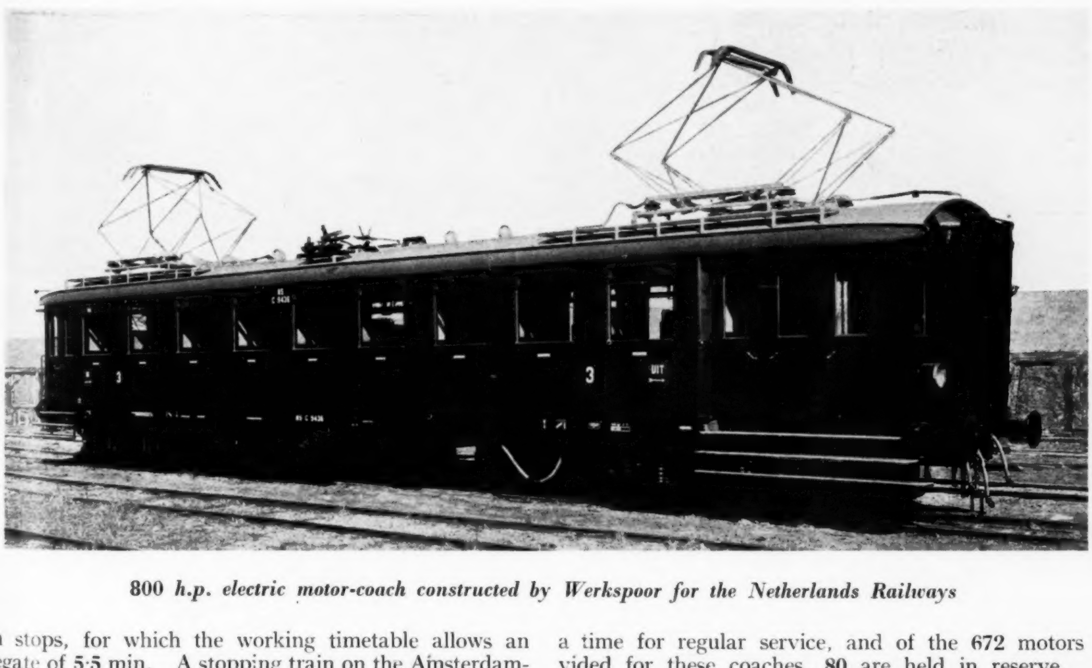
Rolling Stock and Services

Except for the Amsterdam-The Hague-Delft-Rotterdam-Dordrecht line, a large part of the permanent way is unsuitable for speed in excess of 56 m.p.h., but on the above-named division, a maximum speed of 62 m.p.h. is allowed and is maintained for miles on end by the fast trains between Amsterdam and Rotterdam. On the northern section, the trains from Amsterdam to Alkmaar cover the distance of 24·3 miles in 41 min. inclusive of seven stops, for which the working timetable allows an aggregate of 5·5 min. A stopping train on the Amsterdam-Rotterdam line, with an average distance between stops of 2·5 miles, has an average speed of 38 m.p.h. The majority of the fast trains on this line make only four intermediate stops, and average 48·5 m p.h.

Of the trains between the Dutch capital and Rotterdam, 92 per cent. are fast trains making four stops or less, and 8 per cent. are stopping trains; over the Amsterdam-Alkmaar, Haarlem-Uitgeest-Ijmuiden division the proportions are reversed, only 16 per cent. of the total being fast trains and the remainder stopping trains.

The system of bringing all the rolling stock into a shed at night, which was followed by the old South Holland Electric Railway, is not now practised, and it is easy to see that this is not feasible, for the 148 motor-coaches and 155 trailers which make up the stock have an aggregate length of 3·7 miles. The train units remain in the terminal stations overnight; they are sent to the inspection sheds, as a general rule every six days, in which time the stock employed on fast trains has covered from 1,550 to 2,200 miles, or 260 to 370 miles a day.

After running 55,000 to 62,000 miles the motor-coaches are sent to the car works at Haarlem, where the mechanical portions are overhauled. After every other such repair, *i.e.*, after a mileage of 110,000-125,000, the traction motors are overhauled at Leidschendam, at which establishment the general electrical equipment is also overhauled at intervals corresponding to 185,000-280,000 miles. About 95 per cent. of the motor-coaches are available at a time for regular service, and of the 672 motors provided for these coaches, 80 are held in reserve.



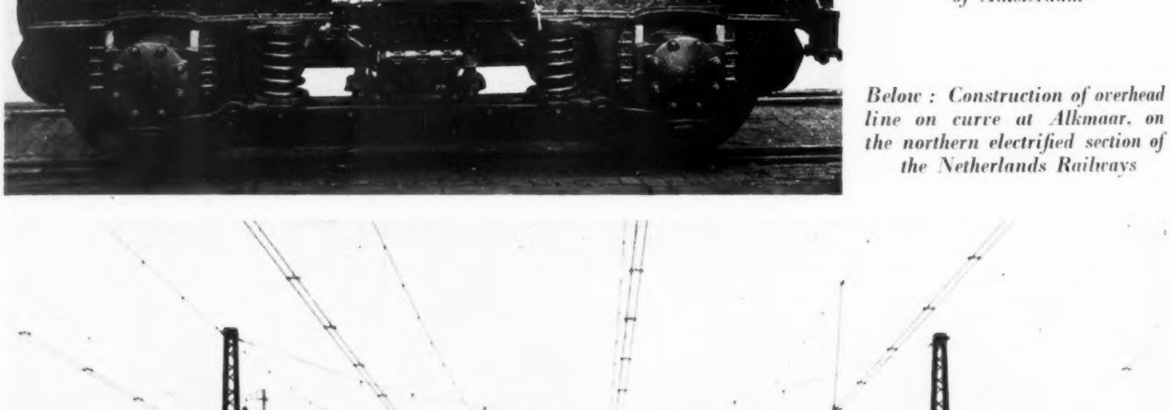
800 *h.p. electric motor-coach constructed by Werkspoor for the Netherlands Railways*

Originally the trains were made up of two motor-coaches with two or three trailer coaches between, but to meet the requirements of growing traffic, a further motor-coach was added. At the present time, however, there is hardly such a thing as a standard make-up, and two, three, four,

Above (left): The new station at Zwijndrecht, on the Rotterdam–Dordrecht section of the Netherlands Railways, which was opened to electric traction on May 15. Right: First electric train at Barendrecht station, on the Rotterdam–Dordrecht line

Left (top): Motor-bogie with two 200-h.p. nose-suspended motors as fitted to the Dutch multiple-unit stock. (Bottom) Carrying bogie for electric trailers. Both of the bogies illustrated were built by the Werkspoor Company, of Amsterdam

Below: Construction of overhead line on curve at Alkmaar, on the northern electrified section of the Netherlands Railways



six, seven, eight and ten-car trains are worked. One of the test trains built for trial purposes over the Leiden-The Hague section in 1925 was completely equipped by the Metropolitan-Vickers Electrical Co. Ltd., and during subsequent years that company received orders for motors and control gear for 45 motor-coaches to the same design.

Some of the motor-coaches weigh 53 tons, but others scale 60 to 62 tons. There are first, second, and third class motor-coaches, and first, second, and third class trailers, but the proportion of first class accommodation is very small. All the cars are of the centre corridor type with vestibuled ends. Each motor-coach is equipped with four nose-suspended motors of 200 h.p. working two in series at 750 volts off the 1,500-volt line current. The control is of the electro-pneumatic type giving automatic acceleration, and every switch has a separate air cylinder with a combined inlet and outlet valve, operated by an electro-magnetic relay. The control circuit works through a 21-cord cable at a tension of 24 volts, except in trains with four motor-coaches, where the tension is raised to 32 volts on account of the greater train length. Heating is effected electrically at the line voltage, each carriage containing two series of 16-element heaters of 450 watts capacity.

The train and tonne-kilometres over the past six years are given in one of the accompanying tables, and further figures supplied by the Netherlands Railways show that the current consumption amounts to 41 watt-hr. per tonne-km. during the winter, and 35·9 watt-hr. per tonne-km. in the summer, equivalent respectively to 67 and 59 watt-hr. per ton-mile, a low figure which results largely from the relatively great distance between stops and the level character of the line. Further tables give valuable data relative to the comparative costs of operation per train-km. and tonne-km. of steam and electric traction, all

Comparative Costs of Steam and Electric Operation on the Netherlands Railways.*

Steam					Electric		
1928	1929	1930			1928	1929	1930
1·73	1·70	1·64	General expenses	£	1·103	1·132	1·060
3·29	3·36	3·30	Wages of train crews	£	0·618	0·645	0·626
—	—	—	Maintenance of overhead equipment	£	0·599	0·240	0·236
—	—	—	,, substations	£	0·224	0·284	0·237
5·06	4·84	5·09	,, rolling stock	£	1·996	2·211	2·227
2·16	2·22	2·36	Cost of fuel and water		—	—	—
—	—	—	,, electric power	£	4·560	5·080	4·800
12·24	12·12	12·39	Total	£	9·100	9·592	9·186
Per 100 loco. km.					Per 100 train km		

* At 7·53 florins to £1.

Operating Cost of Steam and Electric Traction per 1,000 tonne-km.*

		Steam	Electric
General expenses	Pence	12·15	9·60
Wages of train crews ..	,,	23·60	5·45
Maintenance of overhead equipment	,,	—	2·24
,, substations ..	,,	—	2·24
,, rolling stock	,,	33·55	18·90
Cost of fuel and water ..	,,	15·65	—
,, electric power ..	,,	—	33·00
Total ..	,,	84·95	71·43

* At 7·53 florins to £1.

of which figures are due to Ing. H. J. Van Lessen, the Chief of Electric Traction, to whom, along with Ing. J. E. Van Der Burg, who has charge of all the electric rolling stock, we are indebted for facilities for inspecting the electrified system of the Netherlands Railways.

Electrification of the Central Railway of Brazil

The definite signing of the contract with Metropolitan-Vickers Electrical Co. Ltd., whose tender was accepted, in face of keen competition, for the execution of this work, has been awaiting the final decision of the Brazilian Finance Minister for several months. At a recent conference, at which were present as well as the Finance Minister, the Minister of Communications, the General Manager of the Central Railway, and representatives of the Metropolitan-Vickers firm, a study was made of a further and still more favourable scheme for financing the electrification, on a basis which will permit of sterling remittances being effected without placing undue onus on the exchange-market at a time of extreme economic stress.

The main points of this scheme are set out hereunder: First, the total estimate for the work, which amounts to £2,878,733, plus 7,494 contos in Brazilian money, has been divided into two approximately equal portions; secondly, from one of these portions (computed at £1,411,913, plus 7,159 contos) a sum of £115,213, representing expenses payable in Brazil itself (and therefore in local currency), has been deducted, leaving a balance of £1,296,700. The idea is that this latter sum should be liquidated within a space of five years, as follows:—For the first 12 months nothing is to be paid at all; during the ensuing year-and-a-half, monthly payments of £20,000 are to be made; at the conclusion of these 30 months—by which time the suburban sections as far as Bangú and Nova Iguassú should have been electrified and in working order, thus alleviating the exchange-market by virtue of diminished importations of coal and oil-fuel—£38,000 per month is to be remitted, up to the 59th month inclusive, with a small final payment in the 60th month of £4,431. The remainder of the total amount due (*i.e.*, roughly one half) will be met on a similar basis, or in such modified fashion as the country's economic situation may warrant.

Until satisfactory conclusions are reached on technical matters, no definite figures can be given of the amount of work in this country arising from the contract.

ELECTRIC LOCOMOTIVE WHEEL ARRANGEMENTS

The system of notation now used in America is compared with the Whyte method*

By W. D. BEARCE

THE recent action of the American Transit Engineering Association and the American Railway Engineering Association, representing respectively the electric railways and the steam roads, with respect to methods of designating the wheel arrangement of electric locomotives, is the culmination of a long series of conferences by the engineers and railway men most concerned with the subject, and practically standardises for the United States the practice of both manufacturers and users of electric locomotives. The Heavy Traction Committee and the Electric Rolling Stock Committee of the above named associations have both approved the proposed system. In view of the similarity of the American system to that which has been used with some variations in Europe, it is quite within the possibilities that an international standard will later be adopted.

The scheme was put forward by the late Mr. W. B. Potter, who realised that the Whyte system, which had long been used for steam locomotive classification, was unsuited in many ways to the needs of the electric locomotive. This is particularly true with respect to the distinction between the idle and driving wheels. The Whyte system originated with the American Locomotive Company many years ago and has been almost universally used in the United States and the British Empire for designating the wheel arrangement of steam locomotives. It is based on a numerical representation of the number and arrangement of wheels by trucks without any provision for distinguishing between idle wheels and those furnishing the motive power. The Hudson or Baltic type locomotive, for example, is designated as 4-6-4. This indicates four wheels on the forward guiding truck, six wheels on the three main driving axles and four wheels on the trailing truck. For locomotives on which either trailing or leading axles are absent, a cypher is used to convey this information. For instance, for a Mogul, which is built with three main driving axles and a single guiding axle in front, the designation is 2-6-0.

With electric locomotives there are possibilities of a much greater variety of wheel arrangements, both as regards idle trucks and driving trucks, and many designs which would carry the same classification with the Whyte system are altogether different machines. For example, several locomotives built for shunting and mixed service have an idle axle between two drivers on each of the two trucks, and are designated A1A-A1A. On the other hand, the New York Central freight locomotive, which is built with two three-axle driving trucks without idle axles, is designated as a C+C. Both of these locomotives, however, would be characterised by the Whyte system as 0-6-6-0.

Another feature of electric locomotive construction is the frequent use of the multiple-unit principle, by means of which duplicate locomotives are operated in multiple in much the same way as a multiple-unit motor car train. With the new system this characteristic is indicated by expressing the wheel arrangement for a single unit in parentheses, with the number of units outside. Thus, the Virginian locomotive is designated as 3 (1-D-1).

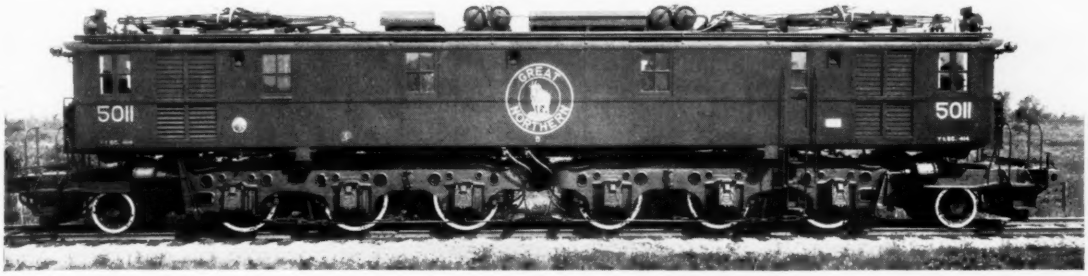
Cleveland Union Terminal passenger locomotive, classification 2-C + *C*-2—300/408—6*GE*278*C*—3000 *V*

The new classification, as used by the General Electric and American Locomotive Companies, is divided into four groups, as follow:—

1. Truck and axle classification.
2. Total weight of motors and total weight of complete locomotive.
3. Motor equipment.
4. Normal supply voltage.

In order to secure the maximum simplicity, the association committees limited the scope of their classification standards to Items 1 and 2. Quoting from the A.R.A. Report: "Starting at the front end of engines designed for single-end operation, or at either end for engines built for double-end operation, the wheels and truck connections are designated in their consecutive order. Letters represent the driving axles, numerals the guiding or carrying axles, and signs the absence or presence of connection between trucks." The capital letter indicating the number of driving axles has the numerical significance of its position in the alphabet. For instance, A denotes one driving axle;

* Editorial comment on this article will be found on page 991.



Great Northern Railroad freight locomotive, classification **1-C + C-1—410/518 – 6GE290A—11000 V**

B, two consecutive driving axles, and so on. In the same way, the number of guiding trucks is indicated by numerals. It frequently happens that a single truck contains both driving and idle axles, and a truck with one idle and one driving axle is designated 1A or A1.

When the connection between the trucks is a coupling through which the pulling stress is transmitted, the designation between the truck symbols is a plus sign. For example, B+B represents a locomotive having two trucks with a coupling between them; B – B represents a locomotive with swivel trucks, in which case the pull is transmitted through the locomotive underframe. The hyphen is also used as a separation between a truck having driving wheels and adjacent guiding trucks not connected through a coupling. For example, 2-D-2 represents a locomotive with a two-axle guiding truck at each end and four driving axles in the centre.

The complete classification system, proposed by Mr. Potter and adopted by the General Electric and American Locomotive Companies, provided, in addition to the above, an indication of the weight of the locomotive and the weight on driving wheels in thousands of pounds. The number of motors was also indicated and, finally, the contact wire or line voltage from which the locomotive was supplied. For example, 2-C+C-2-312/419-6GE278C-3000 V. indicates a weight on drivers of 312,000 lb., a total weight of 419,000 lb., six General Electric 278C motors, and a line supply of 3,000 volts. Provision is also made for designating weights in the metric system as follows: 76/115 MT indicates 76 metric tons on drivers, and a total weight of 115 metric tons. In the English units this would be shown by 167/255, indicating 167,000 lb. and 255,000 lb., respectively.

This scheme of classification lends itself to transcription by means of any ordinary typewriter which carries the plus sign (see table). It will be noted also that no attempt has been made to indicate in this classification the numerous methods of transmitting power from the motor to the driving wheels. These may include geared or gearless motors, individual axle, side rod, automatic spring gear, flexible drives and many others. In general this information is considered essential only when the complete design for the locomotive under study is required.

COMPARISON OF OLD AND NEW WHEEL ARRANGEMENT NOTATION

	New Classification.	Whyte Classification.
Articulated freight	B + B	0-4-4-0
Swivel truck switcher	B - B	0-4-4-0
6-axle freight, articulated	B + B + B	0-4-4-4-0
6-axle freight, swivel	C - C	0-6-6-0
Passenger	2 - D - 2	4-8-4
Passenger, articulated	2 - C + C - 2	4-6-6-4

Although finality in the systems of wheel notation may not yet have been reached, it is considered that this method has certain advantages over the European system, especially for American operating conditions.

Mexican Railway freight locomotive, classification ***B + B + B* – 308/308 – 6*GE*278 – 3000 *V***

MERCURY ARC RECTIFIERS—III.

The operation, performance and control of this important class of apparatus are discussed

THE general principle of mercury arc rectifiers having been explained in the preceding articles of this series, it is now proposed to deal with their operating characteristics and various matters appertaining to the satisfactory performance and control. The voltage and current limits within which mercury rectifiers can be built are remarkably wide, neither additional insulation nor additional current-carrying capacity offering any particular difficulty. Mercury rectifiers have been built to deliver direct current at **30,000** volts and two or three times this pressure could be supplied if necessary; the current (in amperes) in such cases is relatively small. At the other extreme, of heavy current and moderate voltage, the largest rectifier yet built is believed to be an **8,000** kW. unit delivering **16,000** amp. at **500** volts d.c. For traction purposes the d.c. voltage required is usually within the limits **500** to **1,500** volts, and the substation capacity rarely exceeds **1,000-2,000** kW., an output which can be supplied by a single metal-clad rectifier, or by a bank of glass-bulb rectifiers in parallel. Several examples of metal-clad rectifiers for traction service are shown in the accompanying illustrations. Fig. **1** shows the external appearance of the A.E.G. rectifier a sectional view of which was reproduced on p. **245** of the February **9** issue. Fig. **2** shows one of the Brown Boveri rectifiers installed in the new automatic substations of the Amsterdam-Alkmaar and Velden-Uitgeest lines of the Netherlands Railways, as described in another part of this issue. The unit illustrated has a rated output of **1,500** volts **800** amp. d.c., with an overload capacity of **300** per cent. for **40** sec. Further reference is made later to the internal features of the Brown Boveri type of rectifier as used on the Berlin Stadtbahn and illustrated in Fig. **6**.

Voltage and Current Relations

Thanks to the convenience and efficiency of the static transformer the high-tension supply to a mercury rectifier may be at any convenient voltage, regardless of the d.c. voltage required. At the same time, abnormally high pressure supply to individual rectifiers involves more expensive transformers and switchgear so that, where bulk supply from an e.h.t. system is concerned, it may be advisable to reduce this to, say, **10,000** volts in a central substation conveniently situated with regard to the rectifier substations. The ratio between the a.c. voltage applied to the rectifier and the voltage of the d.c. output is, in principle, a physical constant for each particular phase-arrangement of the supply to the anodes. The d.c. voltage is in fact the mean of the anode voltages over a full cycle and, apart from the inherent "voltage regulation," *i.e.*, the variation of voltage with load (further discussed below), the d.c. voltage formerly depended only on the maximum anode voltage and the wave form resulting from the arrangement of the a.c. input. Prior to the days of grid control, the only means of altering the d.c. voltage of a rectifier was by altering the voltage of the a.c. input by using different tappings on the supply transformer, or by other means of producing the same effect. Now, however, grid control of the timing of the ignition or firing of the anodes affords a simple means of altering the d.c. voltage over any desired range from the maximum value to zero, as explained in connection with Fig. **4**.

The current-carrying capacity of a mercury rectifier depends on the sizes of the anodes and on the provision of adequate cooling for the condensation of mercury vapour. Heavy overloads can be carried, approximately as follows: **25** per cent. for **2** hr., **100** per cent. for **10** min., and **200** to **300** per cent. for about ½ min. Additional insulation of the anodes and cathode from the tank or body of the rectifier and increased flash-over distances are required for high compared with low voltage operation, but,

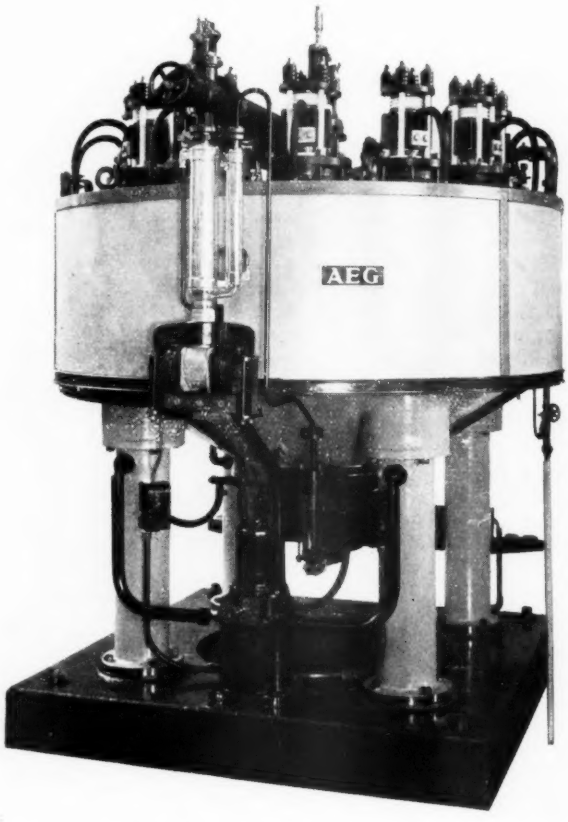


Fig. 1—A.E.G. mercury-arc metal-clad rectifier as used on the Berlin Stadtbahn

within wide limits, the rating of a given rectifier in kW. is proportional to the d.c. voltage. In some cases, as for example in the mercury rectifier substations of the Liverpool-Southport line of the L.M.S. Railway, provision is made for the same rectifiers to be used for a higher d.c. voltage at some future date. Thus rectifiers now rated at **2,000** amp., **600** volts (= **1,200** kW.) will ultimately deliver an equal current at **750** volts (= **1,500** kW.) without any constructional changes, the only modifications required being in such matters as transformer connections, flow and cooling water, and adjustment of voltage relays.

Efficiency and Power Factor

The loss in a mercury rectifier itself, apart from the supply transformer, is mainly the voltage drop in the arc. Usually, this drop is about **20** to **25** volts, and varies little with the rating of the rectifier or the extent to which the apparatus is loaded. The relative importance of the

internal voltage drop is clearly less the higher the d.c. voltage. The efficiency of a rectifier delivering d.c. at V volts, with an internal drop v volts, is practically constant at $100 \times V/(V + v)$ per cent. at all loads. Thus, if v = 20 volts, the efficiency is 91 per cent. when V = 200; 95½ per cent. when V = 400; and 98½ per cent. when V = 1,500 volts. These values exclude the losses in transformers and auxiliaries; assuming a transformer efficiency of 98 per cent. and allowing about 0·5 per cent. for the power consumption of auxiliaries at full-load, the overall

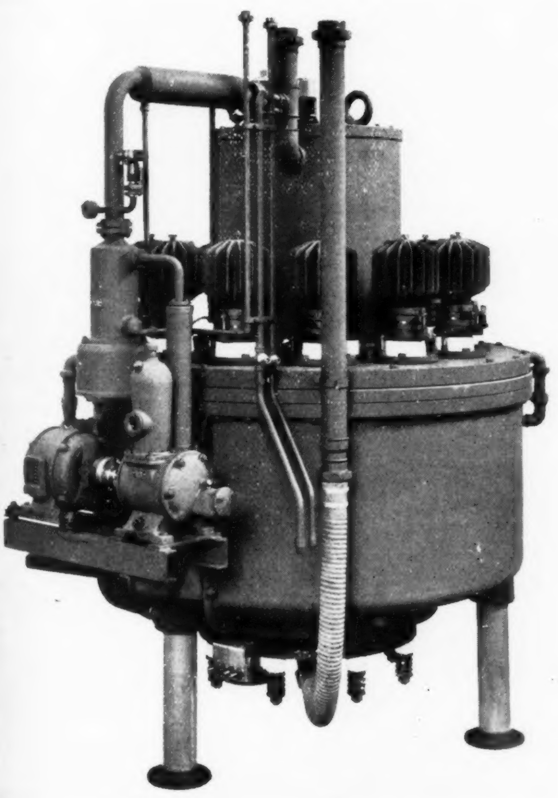


Fig. 2—Brown-Boveri steel-tank rectifier as used by the Netherlands Railways

efficiency is 88·7 per cent. at 200 volts, 93 per cent. at 400 volts, and 96 per cent. at 1,500 volts d.c. output, the values being only slightly lower at quarter-load. The reason for the remarkable efficiency characteristics of mercury rectifiers has been explained at some length because it emphasises the advantage of high-voltage operation and leads to a performance with which rotating machinery cannot compete except at voltages lower than are generally used in traction service. By shortening the arc, modifying the design of anodes and controlling the vapour pressure in the rectifier, the voltage drop in a certain 300-amp., 500-volt rectifier has been made less than 10 volts; on this basis, the mercury rectifier can probably compete economically with rotary converters at 150 to 200 volts.

Lest it should be thought that the efficiency values given above are merely theoretical values, it may be mentioned that the English Electric Company give the following representative values:

D.C. voltage	400	600	1,000	1,500	3,000
Overall efficiency, per cent. ..	92	93	95	96	97·5

Similarly, tests on a British Thomson-Houston metal-clad rectifier, rated at 800 amp., 1,500 volts (= 1,200 kW.) showed efficiencies of 96·4 and 96·5 per cent. at full and ¾-load respectively, without the smoothing circuit and recooler blower motor in operation, this unit serving the Newport-Shildon mineral line of the L.N.E.R.

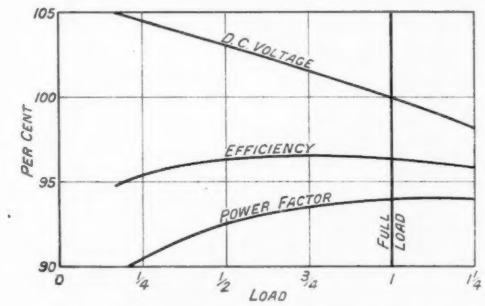


Fig. 3—Operating characteristics of 2,000-kW. 1,650-volt metal-clad rectifier

The small effect of load variations on the efficiency and power factor of mercury rectifiers is illustrated by Fig. 3, relating to the performance of an English Electric rectifier rated at 2,000 kW., 1,650 volts d.c. The efficiency lies within the range 95-96½ per cent. at all loads from ¼ to 1¼ times the rated output. The power factor decreases from

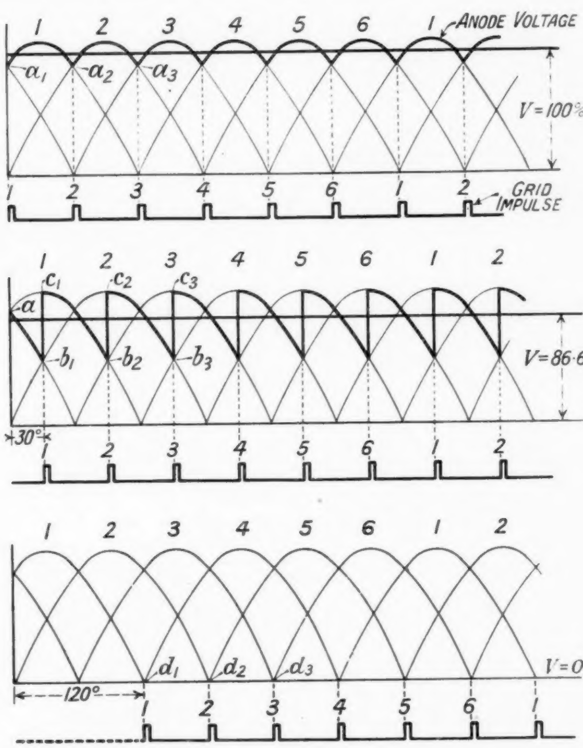


Fig. 4—Diagrams showing the principle of d.c. voltage regulation by grid control in mercury arc rectifiers

about 0·94 at 1-1¼ load to about 0·9 at ¼-load, including the transformer and choking coils; it is always lagging, but not to any objectionable extent. When a heavy reduction of d.c. voltage is effected by grid control, the power factor becomes low, *e.g.*, about 0·6 when the d.c. voltage

is 60 per cent. of normal, but it should be noted that: (1) Operation at such heavily reduced voltage is generally required only temporarily, *e.g.* for the operation of motors at fractional speed; (2) the kVA. input to the rectifier is about the same, or even lower, notwithstanding the reduced power factor, because the kW. output decreases with the voltage, and the decrease in efficiency amounts to only a few per cent.

Voltage Regulation and Control

The term "voltage regulation," in relation to electrical generators, transformers and transmission lines, denotes the percentage rise of voltage occurring when full load is completely removed. As thus defined, the voltage regulation of the mercury rectifier to which Fig. 3 applies is seen to be about 6·0 per cent. The form of the regulation curve is important not only as regards the maintenance of reasonably constant voltage of supply, but also as regards the appropriate division of load between rectifiers, or a rectifier and a converter, operating in parallel. Unless the voltage regulation curves of paralleled units have the same form, the machine or rectifier maintaining the higher voltage will take an undue proportion of the total load. The problem of maintaining any desired voltage-load characteristic for a particular rectifier, and of varying it as required, is completely solved by grid control.

As mentioned above there is, in principle, a definite relation between the d.c. voltage of a rectifier and the a.c. voltage applied to its anodes. In the case of a six-phase rectifier, the d.c. voltage is about 95 per cent. of the maximum or crest value* of the voltage applied to each anode in turn (see upper diagram, Fig. 4) and, as long as natural commutation of the anodes is practised—No. 2 firing and taking over the load as soon as its rising voltage exceeds the falling voltage of No. 1, and so on—the only means of varying the d.c. voltage is by altering the a.c. voltage applied to the anodes. This may be effected by variable tappings on the supply transformer, or by an induction regulator or variable choking coils in the anode leads. Grid control, however, enables the applied a.c. voltage to be kept constant, the d.c. voltage being altered by varying the range of voltage within which each anode fires. This is the purpose to which grid control is at present most extensively applied and, though it is by no means the only application of such control, it fully illustrates the principles involved.

* The effective or r.m.s. value of the anode voltage, as measured by an a.c. voltmeter connected between the anode and the neutral, is 0·707 × the maximum or crest voltage. The d.c. voltage is therefore about 1⅓ times the r.m.s. value of the anode voltage.

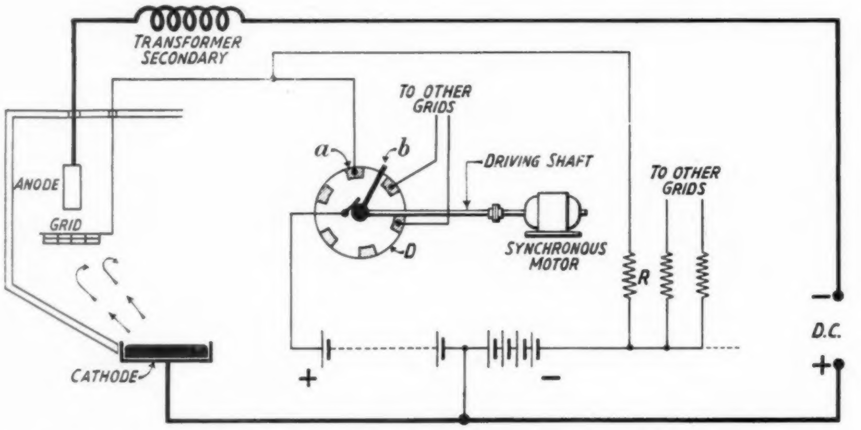


Fig. 5—Diagrammatic representation of the method of controlling the supply and timing of the grid potential of a mercury arc rectifier

As explained in an earlier article (see Fig. 4, p. 443 of this Supplement, March 9, 1934), the screening of an anode by a grid carrying a suitable negative charge prevents electrons from the cathode hot-spot reaching the anode, even though the latter is at a suitable positive potential with regard to the cathode. In other words, a sufficiently negatively charged grid will delay the firing of an anode, No. 2, beyond the natural commutating point, and if the grid in front of the preceding anode, No. 1, be meanwhile kept at a positive potential then the No. 1 anode will continue to burn as long as its potential exceeds that required to maintain the arc (say 25-30 volts). The No. 2 anode will, however, take over the arc as soon as the No. 2 grid is made sufficiently positive relatively to the cathode.

Referring to Fig. 4, the top diagram shows the conditions with natural commutation, the Nos. 1, 2 . . . 6 grids being successively given positive potential at the moments corresponding to a_1, a_2, a_3, &c., when each anode in turn reaches an (increasing) voltage higher than that (decreasing) of the preceding anode. The d.c. voltage is then a maximum, represented by V = 100 per cent. In the centre diagram, Fig. 4, the application of positive grid potential has been delayed by 30 deg. (= $\frac{1}{12}$ cycle, or about 0·0017 sec. in the case of 50-cycle supply). The effect of this is that although the No. 1 anode is still prepared to fire at point *a*, as far as its own potential is concerned, it cannot do so because its grid is still charged negatively. The preceding anode (No. 6) therefore continues to burn until the point b_1 is reached; at this moment, grid No. 1 is made positive, anode No. 1 fires at the maximum potential c_1 and continues to burn, at potential decreasing to b_2 until the No. 2 grid allows the No. 2 anode to fire at c_2, and so on. Though the voltage applied to the anodes is the same as before, the voltage of those anodes which are burning follows the serrated curve *a*, b_1, c_1, b_2, &c., and the d.c. voltage, being the average of the burning-anode voltage, is V = 86.6 per cent. In the bottom diagram, Fig. 4, the grid impulses have been further delayed to 120 deg., and no anode is given an opportunity of firing (by its grid being made positive) until the voltage of the anode has reached zero. Obviously, none of the main anodes can fire under these conditions, notwithstanding the fact that the steadily burning ignition anodes maintain a cathode hot spot and a discharge of electrons therefrom. The d.c. voltage is therefore now zero, V = 0. Any d.c. voltage from the maximum to zero can thus be obtained by altering the timing of the grid positive potentials and, apart from the requirements of ordinary voltage control, parallel operation and compounding, the method enables the speed of d.c. motors

to be varied by variable-voltage supply, without rheostatic losses.

One method of supplying and timing the appropriate grid potentials is shown diagrammatically in Fig. 5. An insulating disc D carries equally spaced contact plates *a* connected each to one grid in the order in which the anodes are to fire. Only one anode and grid are shown in Fig. 5 for simplicity. Each grid is connected through a resistance R to the negative terminal of a battery which normally keeps the grid negative with respect to the cathode and thus prevents electrons from reaching the anode concerned. The contact arm *b* is rotated by a synchronous motor, supplied from the same source as the rectifier, and when *b* touches *a* the grid is connected to the positive terminal of the grid battery and the anode is then free to fire. At the same time, the positive terminal of the grid battery is connected to the lead from R, and the object of the resistance R is to obviate what would otherwise be a short-circuit across the battery. The rotating brush and contact disc causes the grids to be charged positively in the correct sequence and at the correct intervals, and, by moving the contact disc forwards or backwards, the phase of the ignition point can be altered as indicated in Fig. 4. The application of a suitable impulse of positive potential to the grid ensures instant firing regardless of variations in the anode ignition voltage due to changes in load and temperature, and thus effects "hard" control as distinct from the "soft" and less definite control which results from the application of a sinusoidal potential to the grid.

Backfire and Vacuum

The occurrence of a backfire in a rectifier, *i.e.*, a flow of current from the cathode to an anode which is at the moment negative with regard to the cathode, short circuits the transformer phases to which the firing and backfiring anodes are connected. This risk has been practically eliminated in modern rectifiers by improvements in the cooling arrangements and in the arrangement of the anodes. If a backfire should occur, say by extreme overload forming a hot-spot on one of the anodes, it can be cleared by a high-speed overload relay which applies negative potential to all the grids. A short-circuit current exceeding 23,000 amp. on an English Electric rectifier delivering 2,340 amp. at 795 volts has been cleared by this method in one-fiftieth of a second.

The sectional drawing, Fig. 6, shows clearly the arrangement of sheet iron anode shields A protecting the anodes from condensation of mercury and, in conjunction with the funnels D, E (insulated from the chamber), providing that the arc can flow only along the paths determined by the anode potentials and clear of the walls. In this particular rectifier there are 12 anodes, connected in pairs in parallel to a six-phase transformer; normally, there are always two main arcs burning, and the auxiliary anode B ensures that the rectifier is not shut down by a temporary absence of load. The spout S carries condensed mercury to the side of the chamber and so back to the cathode C. The anode heads are air-cooled and the provision made for water-cooling the chamber is evident from the drawing. The vacuum connection is at V and the two vacuum pumps, a high-vacuum mercury-jet pump and a rotary pre-evacuating or roughing pump, are mounted on the side of the rectifier at P, the connections being thus short. Further notes on the maintenance of vacuum and the operation of glass-bulb and metal clad rectifiers will be given later.

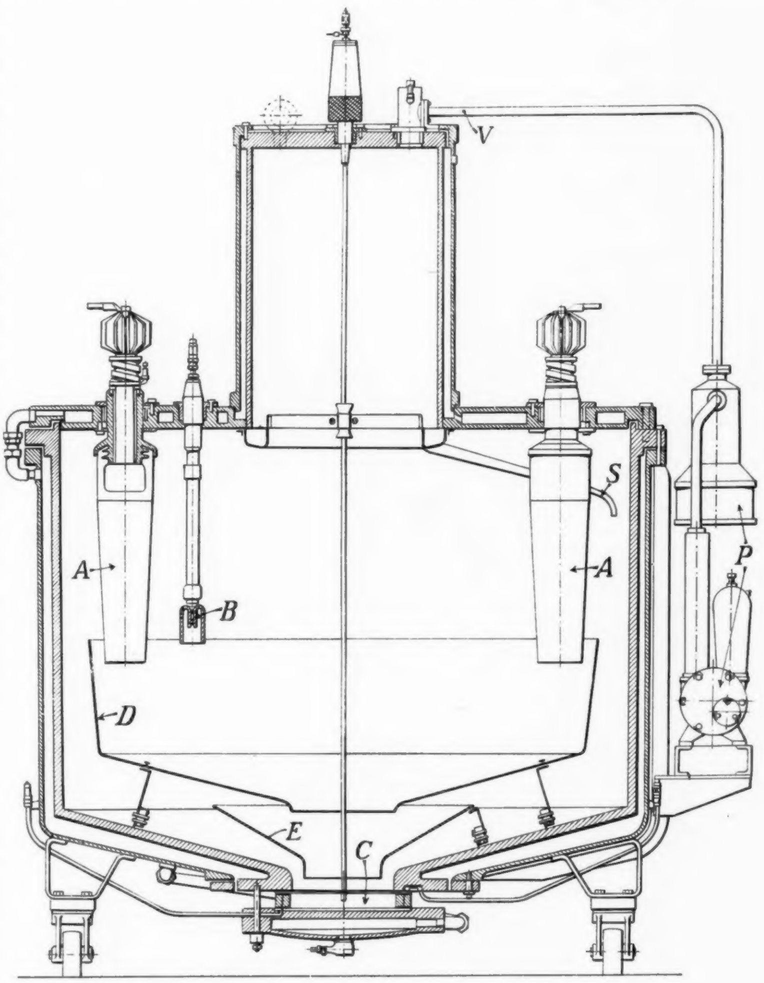


Fig. 6—Section through Brown-Boveri metal-clad rectifier as used on the Berlin Stadtbahn

Belgian Electrification.—In order to carry out certain works, mainly in connection with the Brussels-Antwerp electrification, the Belgian National Railways are seeking authorisation to borrow 812,000,000 fr. (£4,600,000 at par). The total track mileage to be electrified under this programme is 56, and the current used will be 3,000 volts d.c. converted from high-tension three-phase by mercury-arc rectifiers. Each motor-coach is to be fitted with four 200-h.p. motors working two and two in series at 1,500 volts per commutator. For the opening in 1935, 12 trains will be available, each comprised of two motor-coaches and two trailers, and it is anticipated that with a full passenger service the annual current consumption will be in the neighbourhood of 15,000,000 units.

ADHESION EFFICIENCY OF ELECTRIC LOCOMOTIVES

Heavy American shunting design with weight-transfer compensation

Heavy shunting locomotive with control for adjusting the tractive effort

IT is well known that in normal double-bogie electric locomotives with four nose-suspended motors the torque reaction of the motors results in weight being transferred from the leading to the rear axle of each truck. In addition, the drawbar reaction sets up a couple which tends to relieve the front end of the locomotive and load the rear end. The conditions become worse as more and more tractive effort is applied, until the leading wheels of each bogie commence to slip.

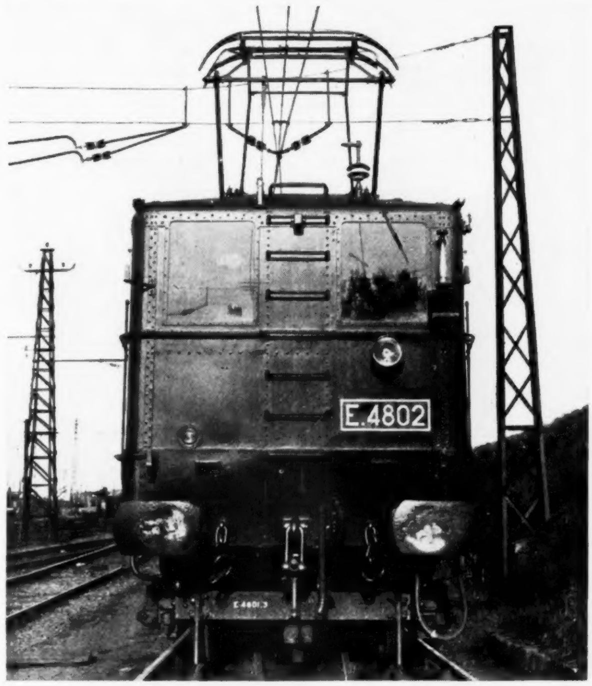
With a view to nullifying this effect and obtaining 100 per cent. adhesion efficiency, the Westinghouse Electric & Manufacturing Company some time ago incorporated a weight-transfer compensation feature in four 90-ton double-bogie switching locomotives built for service in the Markham hump yard of the Illinois Central Railroad. These locomotives have a normal maximum tractive effort of 50,000 lb., corresponding to 25 per cent. adhesion, but to make full use of the adhesion the tractive effort of the leading axle of each truck is reduced from 12,500 to 11,000 lb., and that of the trailing axles raised to 14,000 lb., the weights and tractive efforts under maximum pull being as follows:—

	First axle	Second axle	Third axle	Fourth axle
Static rail load, lb. ..	50,000	50,000	50,000	50,000
Nominal tractive force, lb.	12,500	12,500	12,500	12,500
Weight transfer, lb. ..	− 7,650	+ 6,420	− 6,420	+ 7,650
Adjusted tractive force, lb.	11,000	14,000	11,000	14,000

The adjustment in tractive effort is easy to obtain, especially with full series motor combination, and is effected by operating the leading motors of each truck with reduced field and the trailing pair with full field. The armature current of all the motors is the same, but the active field-ampere turns in the leading motors are reduced, and this occasions a decrease in the tractive effort. Although it is possible to arrange the main control apparatus to obtain the adjustment in tractive effort on every start, it was not thought advisable to do this on the Illinois Central locomotives, as it increases the power demand when starting trains light enough to be handled without the use of this feature. The control scheme for the adjustment has therefore been arranged for manual operation, and a push-button switch has been mounted near the main controller for operation by the driver when necessary. It is, however, easy to connect the tractive effort adjustment control to the sanding gear switches, so that the feature operates whenever sand is applied to the rail.

Train weights up to 1,800 tons are dealt with by these locomotives when operating in yards, but for short-distance transfer work, two of them are coupled together and haul 3,600-ton trains at speeds up to 30 m.p.h. on the level. Multiple-unit control being fitted, one man can operate the two locomotives. All the switches at line pressure (1,500 volts d.c.), are remotely controlled by electro-pneumatic switches in the main control circuit, but the control circuits are worked from a 32-volt supply provided by two generators and a floating battery. The principal particulars of these Illinois Central locomotives are: h.p. on hourly rating, 1,450; length overall, 40 ft. 1 in.; total wheelbase, 27 ft. 3 in.; bogie wheelbase, 8 ft. 7 in.; wheel dia., 45 in.; weight in working order, 90 tons; max. speed, 40 m.p.h.; minimum curve, 175 ft. radius.

Above: The double-unit 2,400-h.p. Metropolitan-Vickers electric locomotive of the South African Railways which was specially painted and decorated for the haulage of Prince George's train in Natal during his recent tour in South Africa



Right: End view of one of the 2-D_0-2 1,500-volt express electric locomotives of the Midi Railway. These machines were described in "The Railway Gazette" for March 31, 1933

Below: An express train between New York and Philadelphia hauled by one of the 3,750-h.p. 2-C_0-2 electric locomotives of the Pennsylvania Railroad, which were described in this Supplement for November 17, 1933

THE ADHESION CHARACTERISTICS OF LOCOMOTIVES EQUIPPED WITH AXLE-HUNG MOTORS

The alteration in the adhesion weight of electric locomotives is an important matter, and is discussed in detail in this article

By F. WHYMAN, B.Sc. (Tech.), A.M.I.E.E.

IT is generally understood that the maximum tractive effort that can be exerted by an axle-hung locomotive without slipping of the wheels, is less than is to be anticipated from consideration of the coefficient of friction between wheel and rail and the transfer of weight due to the exertion of the tractive effort at the height of the drawgear above rail level, but it does not appear to be so generally appreciated that this disparity is due to inherent characteristics of the axle-hung motor, and that by suitable disposition of the motors on the axles and a suitable choice of the mechanical arrangement of the locomotive, this disparity can be eliminated and a much larger tractive effort obtained.

Torque Reaction of the Axle-Hung Motor

Consider the case of an axle-hung motor driving an axle where:—

T is the tractive effort exerted between wheel tyre and rail, in tons.
r is the radius of the driving wheel, in feet.
S is the distance in feet between axle centre and motor nose.

To produce the tractive effort T, the motor must exert a turning moment T × r on the axle, and to hold the motor body in equilibrium, the wheel, axle, and the nose suspension must exert an equal and opposite turning moment on the motor body. The reactions of these forces are a force F exerted by the motor axle-bearing on the axle, and the motor nose on the truck. The value of the force F is given by the fact that the turning moment F × S must equal the turning moment T × r. Therefore F = T × r/S.

Where the nose suspension is approximately on the same level as the axle, F represents a vertical force increasing or decreasing the pressure between wheel and rail. Fig. 1 illustrates this for the different senses of motion. In a typical axle-hung motor where r is 2·0 ft., S is 3·8 ft., and the axle load is 16 tons, the value of the force F is 2·1 tons when T is 25 per cent. of the axle load.

The Effect of the Force F on the Rail Reactions of the Different Axles

To illustrate the disturbing effect of this force F on the rail reactions of the various axles of a locomotive when exerting effort, the results shown in Fig. 2 have been worked out for different arrangements of motor disposition and spring system, of otherwise identical locomotives. The following figures give the general characteristics of the locomotive:—

Overall wheelbase	30·916 ft.
Truck wheelbase	9·25 ,,
Distance between two middles axles	12·416 ,,
Truck centres	21·666 ,,
Total weight of locomotive	67·00 tons.
Normal rail reaction of each axle	16·75 ,,
Deadweight per axle	3·00 ,,
Radius of driving wheels	2·00 ft.
Distance between motor nose and axle bearing	3·80 ,,
Height of drawbar above rail	2·875 ,,
Height of centre pivot of truck above rail	3·55 ,,

The examples in Fig. 2 have been worked out to show the individual rail reactions of the different axles when the locomotive is exerting a tractive effort equal to 25 per cent. of its dead weight, *i.e.*, 16·75 tons, and take into account the turning moment due to the exertion of tractive effort at the height of the drawbar above the rail, and the effect of the motor reaction force F. When the tractive effort per axle is 4·19 tons, the force F is 2·2 tons. The diagrammatic sketches of the different spring systems and motor arrangements in Fig. 2 are easily understood. The first example denotes a double-bogie locomotive in which the motors of each bogie are mounted with their noses pointing towards each other. The springs of the two axles of each bogie were equalised and the bogies are provided with end bearers in contact with the locomotive body. The second example represents an identical locomotive, with the exception that the axles of each bogie are not equalised. The last two examples have free centre pivot bogies. The last but one represents normal American practice, and the last example represents the present general practice with suburban driving motor-coach stock. For each example in Fig. 2, the lowest rail reaction is marked with a cross, and this rail reaction is indicated in the column on the extreme right as a percentage of the normal rail reaction of 16·75 tons. This percentage column can be taken as a ratio of the tractive efforts possible with each arrangement without slipping.

As an illustration of the method of calculation, the

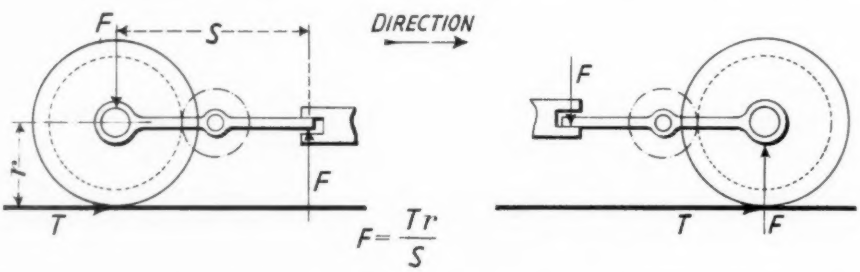


Fig. 1—Diagram showing vertical forces on driving axle and through the motor nose suspension

SPRING PRESSURES-TONS				ARRANGEMENT	RAIL REACTIONS				
13·92	13·92	13·58	13·58		19·12	14·72	18·78	14·38 x	85·8%
13·96	13·83	13·67	13·54		19·16	14·63	18·87	14·34 x	85·6%
12·65	12·65	14·85	14·85		17·85	17·85	15·65 x	15·65 x	93·4%
12·44	13·22	14·28	15·06		17·64	18·42	15·08 x	15·86	90·0%
17·05	17·05	10·45	10·45		17·85	17·85	15·65 x	15·65 x	93·4%
17·75	15·36	12·14	9·75		18·55	16·16	17·34	14·95 x	89·2%
12·66	12·66	10·44	10·44		17·86	17·86	15·64 x	15·64 x	93·3%
12·89	12·09	11·01	10·21		18·09	17·29	16·21	15·41 x	92%
15·8	15·8	11·7	11·7		16·6	21·0	12·5 x	16·9	74·6%
16·23	14·75	12·75	11·27		17·03	19·95	13·55 x	16·47	80·9%
14·15	13·35	14·15	13·35		19·35	14·15 x	19·35	14·15 x	84·4%
14·5	12·48	15·02	13·0		19·7	13·28 x	20·22	13·8	79·2%
NORMAL SPRING PRESSURE = 13·75 TONS					NORMAL RAIL REACTION = 16·75 TONS				

Fig. 2—Rail reactions of double-bogie locomotive

detailed calculation of the first example in Fig. 2 is given below:—

Let P_1 = spring pressure of each trailing bogie axle.
Let P_2 = spring pressure of each leading bogie axle.

The springborne portion of the locomotive weight is 67 − 12 = 55 tons.

Then
$$2P_1 + 2P_2 = 55$$
$$P_1 + P_2 = 27 \cdot 5 \quad \ldots\ldots\ldots\ldots \quad (1)$$

Reading from left to right, the rail reactions of the various axles must be:—

$$(P_1 + 3 + 2\cdot2),\ (P_1 + 3 - 2\cdot2),\ (P_2 + 3 + 2\cdot2),\ (P_2 + 3 - 2\cdot2)$$

which are:—

$$(P_1 + 5\cdot2),\ (P_1 + 0\cdot8),\ (P_2 + 5\cdot2),\ (P_2 + 0\cdot8)$$

As the locomotive, as a whole, is in equilibrium, the sum of the moments of the rail reactions of all axles about the centre of the locomotive must be equal to the counter-clockwise moment 16·75 × 2,875 (drawbar height) = 48·2 tons-feet. Therefore,

$$(P_1 + 5\cdot2 - P_2 - 0\cdot8)\ 15\cdot458 + (P_1 + 0\cdot8 - P_2 - 5\cdot2)\ 6\cdot208 = 48\cdot2$$
$$\therefore P_1 - P_2 = 0\cdot346 \quad \ldots\ldots\ldots\ldots \quad (2)$$

From (1) and (2) it follows that P_1 = 13·923 tons, and P_2 = 13·577 tons.

The various rail reactions are, therefore, as follow:—

$$(13\cdot923 + 5\cdot2),\ (13\cdot923 + 0\cdot8)$$
$$(13\cdot577 + 5\cdot2),\ (13\cdot577 + 0\cdot8)'$$

which are:—

19·123 tons, 14·723 tons, 18·777 tons, 14·377 tons.

As the normal rail reaction is 16·75 tons, and the lowest reaction above is 14·377 tons,

$$\text{then} \quad \frac{14\cdot377}{16\cdot75} \times 100 = 85\cdot8 \text{ per cent.}$$

Fig. 3 illustrates this example in greater detail.

General Inferences

From the foregoing remarks and the comparisons shown in Fig. 2, it will be obvious that in the case of locomotives of the type shown in Fig. 3, the best adhesion results can only be obtained by arranging the two motors of each bogie so that they both point the same way. Fig. 2 shows that if the motors of the locomotive in Fig. 3 are rearranged so that the motors of a bogie both point the same way, about 9·0 per cent. more tractive effort can be obtained for the same weight of locomotive. The result obtained in this case is exactly the same as if motors other than axle-hung were used, such as the type mounted rigidly on the body of the bogie and driving the axles through flexible couplings. In such cases the only factor disturbing the rail reactions is that due to the tractive effort at the height of the drawbar.

Referring to the example shown in Fig. 2, which is typical of general practice with suburban motor-coach stock, it will be obvious that the disposition of the motors on the axles will have no effect on the rail reactions of the various axles, as the bogies have free spherical pivots and no end bearers. Re-disposition of the motors would merely affect the spring pressures on the various axles, or, in other words, change the angle of tilt of the bogies. It will be remarked, however, that 18 per cent. more tractive effort could be obtained for the same locomotive weight by adopting the third arrangement shown in Fig. 2.

Locomotives with Six Driving Axles

Another very common form of locomotive is that employing two articulated trucks, each having three axles

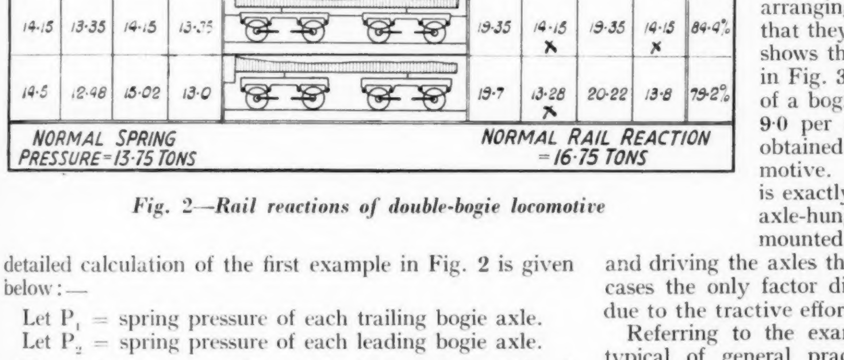


Fig. 3—Rail reaction forces in double-bogie locomotive with compensated springs and steady bearers

driven by axle-hung motors. Very good adhesive results should be obtained with such a locomotive as the disturbing effect of the drawbar pull at a height above rail level is largely discounted by the increased total wheelbase. Very disappointing results have, however, often been obtained with this type of locomotive, and in such cases it is found that the motors have been arranged in such a way that the effect of the torque reaction forces of the axle-hung motor causes a particular axle to have a very poor rail reaction. In this type of locomotive, the three motors of each truck should be arranged so that they all point the same way. Also the springs of all three axles should be equalised and front and rear end bearers provided. The adhesion of such a locomotive is then equal to that of a similar locomotive driven by flexible coupling motors mounted on the truck frame.

Instances occur in certain locomotive arrangements where the torque reaction forces of the axle-hung motor can be arranged to maintain the rail reactions of the driving axles constant, irrespective of the tractive effort exerted. Fig. 4 illustrates such an example. A locomotive of this axle arrangement, incorporating four driving and two idle axles, is not uncommon for passenger locomotives where the higher speed renders a leading idle axle advantageous for good riding qualities.

For the condition where the rail reactions of the driving axles do not vary, it is necessary to arrange the two motors of each truck so that they both point to the idle axle. In addition, the springs of all three axles of each truck must be equalised and the ratio of equalisation between the driving and idle axles must be chosen in the following manner:—For the driving axle rail reaction to remain unchanged, the spring pressure on the trailing driving axles must increase by $\frac{T \times r}{S}$, and that on the leading driving axles must decrease by this amount. Thus the rail reaction of the trailing idle axle increases by $\frac{T \times r}{S} \times \frac{y}{x}$ and that of the leading idle axle decreases by this amount. This exerts a clockwise couple of $\frac{T \times r}{S} \times \frac{y}{x} \times b$ on the locomotive, which must equal the counter-clockwise couple $4T \times h$ exerted by the drawbar pull (4T) being h feet above the rail level. The necessary condition, therefore, is

$$\frac{T \times r \times y \times b}{S \times x} = 4 \times T \times h$$

$$\text{therefore } \frac{x}{y} = \frac{r \times b}{4\,S \times h}$$

The notation above is the same as used previously, with the addition of h, which is the distance above rail level of the drawbar. The same result can be obtained where more than four motors are used. The necessary equalisation condition, where N is the total number of motors, is that

$$\frac{x}{y} = \frac{r \times b}{N \times S \times h}$$

It will be appreciated, from the foregoing remarks, that careful study of each particular case enables the bad effect of the torque reaction forces of the axle-hung motor on the adhesion characteristics to be eliminated, and in some cases advantage can be taken to maintain the rail reactions constant when tractive effort is being exerted. As the modern traction motor and equipment produce considerably more power for a given weight than their predecessors, the weight of a modern locomotive is generally governed by the weight necessary to allow a certain tractive effort to be exerted without slipping. Thus a locomotive designed on the lines described, to have the greatest possible adhesion, may have a lower weight than would be required with an unfavourable disposition of the axle-hung traction motors. This results in a cheaper and more economical locomotive, and in cases where axle loads are restricted, may enable a four-axle locomotive to be adopted instead of a six-axle locomotive.

On systems where axle loads exceeding the normal are dangerous to structures, it will be seen that rail reactions more than 2·0 tons above the nominal occur during acceleration with certain types of axle-hung motor locomotives. Conversely, where locomotives with inherently bad rail reaction characteristics have been found safe from the track point of view, an increased nominal axle loading can be allowed with a carefully designed locomotive. In the case of suburban motor-coaches, calculations indicate that a motor-coach arranged on the lines described to obtain the best adhesion characteristics, can exert 15 to 20 per cent. greater tractive effort than the normal unit. The proper utilisation of the adhesion suggests the possibility of using a greater proportion of trailer to driving units, resulting in a cheaper and more economical train make-up.

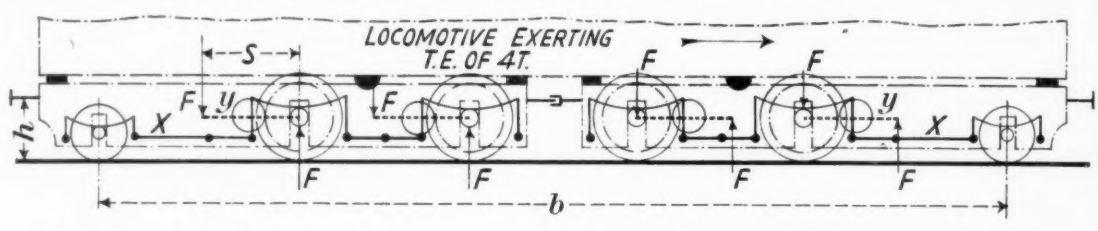


Fig. 4—Diagram showing how rail reactions may be maintained constant with nose-suspended motors

South African Suburban Line Opened.—As foreshadowed in the issue of this Supplement for February 9 last, electric operation over the Cape Flats line from Maitland to Dieprivier, on the Capetown suburban system, was commenced at the end of April. Except for the short single-track line from Pinelands to Langa, which is a branch of the Cape Flats line, and the branch from Salt River to Tygerberg, all the lines centring on Capetown are now electrified, although, of course, long distance trains are still hauled into and out of Capetown by steam locomotives.

Swedish Railway Works.—It is reported that the Riksdag has agreed to the proposals to electrify the following lines, at an estimated total cost of Kr. 25,500,000:—Laxaa to Charlottenberg on the Norwegian frontier, 126 miles; Sodertalje on the Stockholm-Gothenburg line to Eskilstuna and Straengnaes, 60 miles; and Upsala to Gaefle, 71 miles. A further sum of Kr. 13,400,000 is being allowed for the continuation of conversion work on the Stockholm-Aange and Krylbo-Orebro lines.